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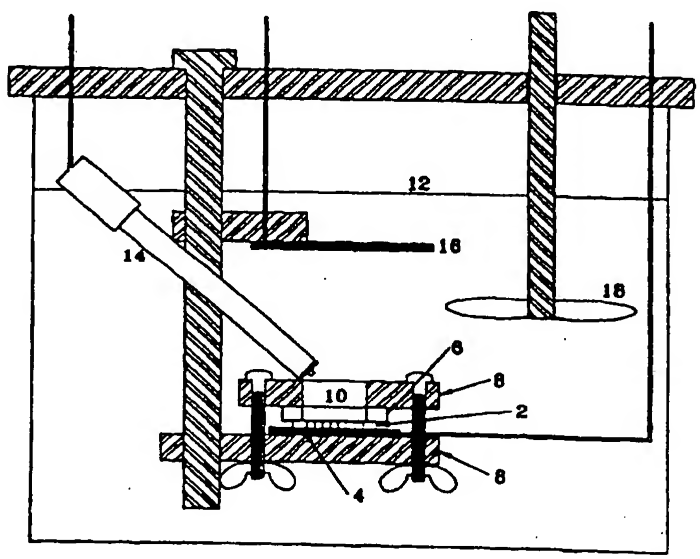
(54) Title: HIGH ASPECT RATIO, MICROSTRUCTURE-COVERED, MACROSCOPIC SURFACES

(57) Abstract

An apparatus and method are disclosed for forming high aspect ratio microstructures ("HARMs") on planar or nonplanar surfaces, using a modification of the LIGA microfabrication process. A free-standing polymer sheet (2) is lithographically patterned with through-holes. The polymer sheet is then pressed against, clamped to, or otherwise attached to a conductive substrate (4) in such a way that the patterned holes in the sheet are not blocked. Subsequent electroplating produces well-defined HARM structures on the planar or nonplanar surface, in shapes that are complementary to the lithographically patterned through-holes in the polymer. The polymer may then be removed (e.g., by melting, dissolution, or burning). Various planar and nonplanar surfaces have been covered with microstructures (6). Where the metal surface is non-planar, the polymer sheet may be heated or otherwise made sufficiently flexible to conform to the metal surface, preferably by heat shrinking to assure firm contact. The process may be used to electroplate microstructures directly onto metal surfaces generally, not just onto metal surfaces that have been specially prepared for LIGA processes, as has previously been the case.



HIGH ASPECT RATIO, MICROSTRUCTURE-COVERED, MACROSCOPIC SURFACES

TECHNICAL FIELD

This invention pertains to macroscopic surfaces whose properties are altered by being covered with microstructures, and to an apparatus and method useful in manufacturing such surfaces.

BACKGROUND ART

The properties of many macroscopic structures depend in large part on their surface properties. For example, the rate of heat transfer between a structure and its surroundings depends on the ease with which radiative, conductive, and convective heat transfer occur between the surface of the structure and the surroundings. As another example, the strength of composite materials is often governed by the strength of the bond between the "internal" surfaces joining the different lamina. As yet another example, the rate of activity of a catalytic surface often depends on its surface area.

Efforts have been made to control the interaction of surfaces with their surroundings by painting, roughening, anodizing, hardening, plating, smoothing, and the like. In many cases, the resulting improvements in surface properties are relatively small.

One area where surface effects are important is the operation of gas turbines. The efficiency and power of a turbine increase as the maximum allowable gas inlet temperature increases. This allowable inlet temperature is a function of the composition of the turbine blades, and the balance of various modes of heat transfer into and out of the blade. Internal active cooling of turbine blades (a mode of heat removal), coupled with thermal barrier coatings on their surfaces (limiting heat transfer into the blades), allows the blades to operate at a relatively low temperature in an environment hundreds of degrees higher. A reduction in the rate at which heat is transferred from the surrounding combustion gases to the blade would allow operation at higher temperatures and efficiencies.

Both the thermal efficiency and the power output of a turbine rise as the pressure ratio and the accompanying inlet temperature increase. For example, using estimates of turbine

I claim:

1. A method for producing microstructures on a metal surface, comprising the steps of:

(a) securing to the metal surface a non-conductive sheet; wherein there is no gap or there is a negligible gap between the metal surface and the non-conductive sheet; wherein the non-conductive sheet contains a plurality of holes; wherein the holes are formed in the non-conductive sheet at a time when the non-conductive sheet is not in contact with the metal surface; and wherein the non-conductive sheet is not chemically bonded to the metal sheet; and

(b) electroplating metal onto the metal surface within the holes of the non-conductive sheet;

whereby metal microstructures are produced on the metal surface.

2. A process as recited in Claim 1, wherein the metal surface is non-planar.

3. A process as recited in Claim 1, wherein the non-conductive sheet comprises a polymer.

4. A process as recited in Claim 3, wherein said securing step comprises heat-shrinking the polymer sheet onto the metal surface.

5. A process as recited in Claim 3, wherein the polymer sheet comprises poly (methyl methacrylate).

6. A process as recited in Claim 1, wherein at least some of the holes in the non-conductive sheet have an aspect ratio greater than about 5.

7. A process as recited in Claim 1, additionally comprising the step of removing the non-conductive sheet from the metal surface after said electroplating step.

8. A process as recited in Claim 1, wherein the non-conductive sheet is a ceramic.

9. A metal surface with microstructures produced by the process of Claim 1.

10. A method for producing microstructures on a metal surface, comprising the steps of:

(a) chemically bonding to the metal surface a polymer sheet; wherein there is no gap or there is a negligible gap between the metal surface and the polymer sheet; wherein the polymer sheet contains an exposed, developable, but undeveloped latent image of a plurality of holes or structures; wherein the latent image is formed in the polymer sheet at a time when the polymer sheet is not in contact with the metal surface;

(b) developing the latent image to produce a plurality of holes or structures in the polymer sheet, without substantially affecting the chemical bonding between the metal surface and the polymer sheet;

(c) removing the chemical bonding agent from the metal surface within the holes in the polymer sheet, without substantially affecting the chemical bonding between the metal surface and the undeveloped portions of the polymer sheet; and

(d) electroplating metal onto the metal surface within the holes of the polymer sheet;

whereby metal microstructures are produced on the metal surface.

11. A process as recited in Claim 10, wherein the metal surface is non-planar.

12. A process as recited in Claim 11, additionally comprising the step of heat-shrinking the polymer sheet onto the metal surface.

53. A composite material as recited in Claim 52, wherein:

(a) said proximal face of said first layer is connected to the proximal ends of each of a plurality of at least about 100 microstructures per cm^2 of surface area of the proximal face of said first layer;

(b) the distance between the proximal and distal ends of each of said microstructures is between about 0.1 mm and about 0.5 mm, and the aspect ratio of each of said microstructures is at least about 10; and

(c) each of said microstructures is closer to the nearest neighboring microstructure than a distance of about 5 times the width of said microstructure.

54. A composite material as recited in Claim 52, wherein the shape of said microstructures is such that said microstructures are physically interlocked securely with said second layer, even disregarding any chemical bonding that may exist between said microstructures and said second layer.

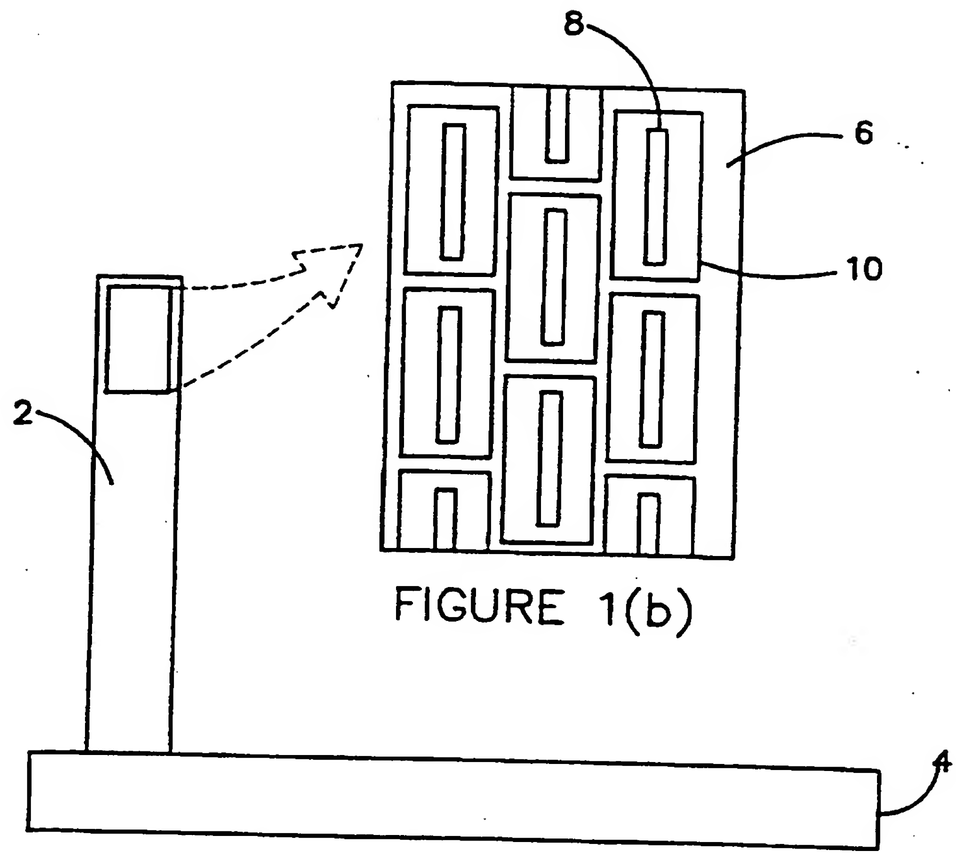


FIGURE 1(b)

FIGURE 1(a)

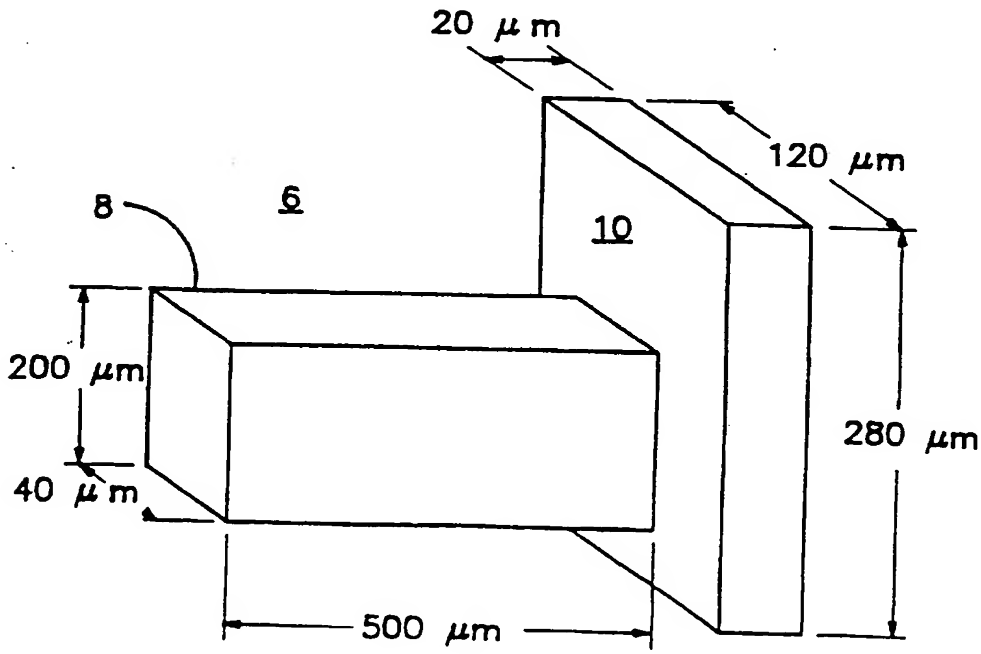


FIGURE 2

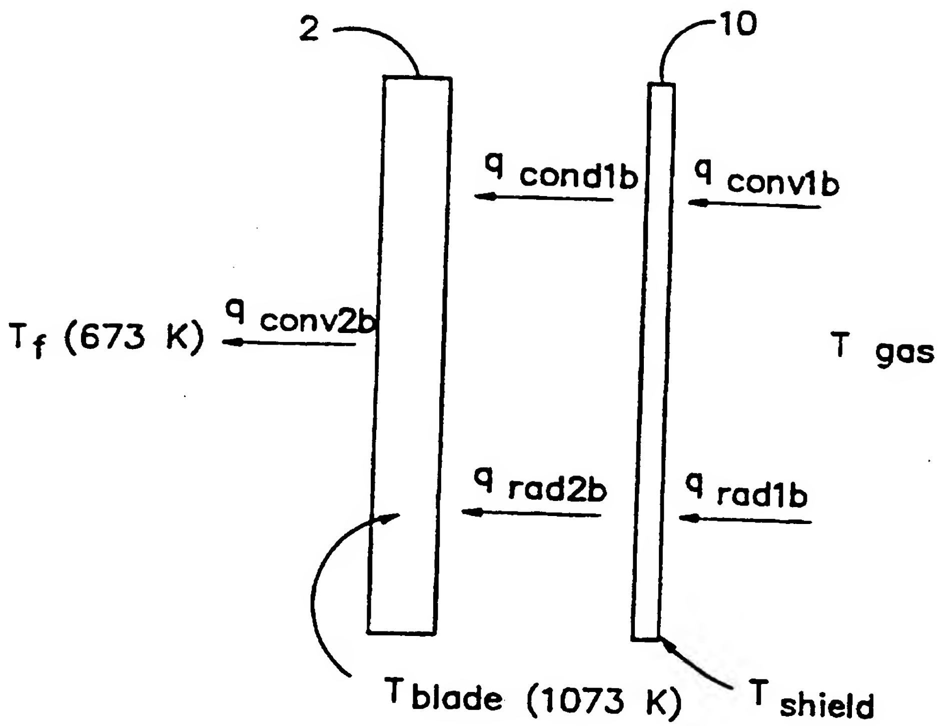


FIGURE 3(a)

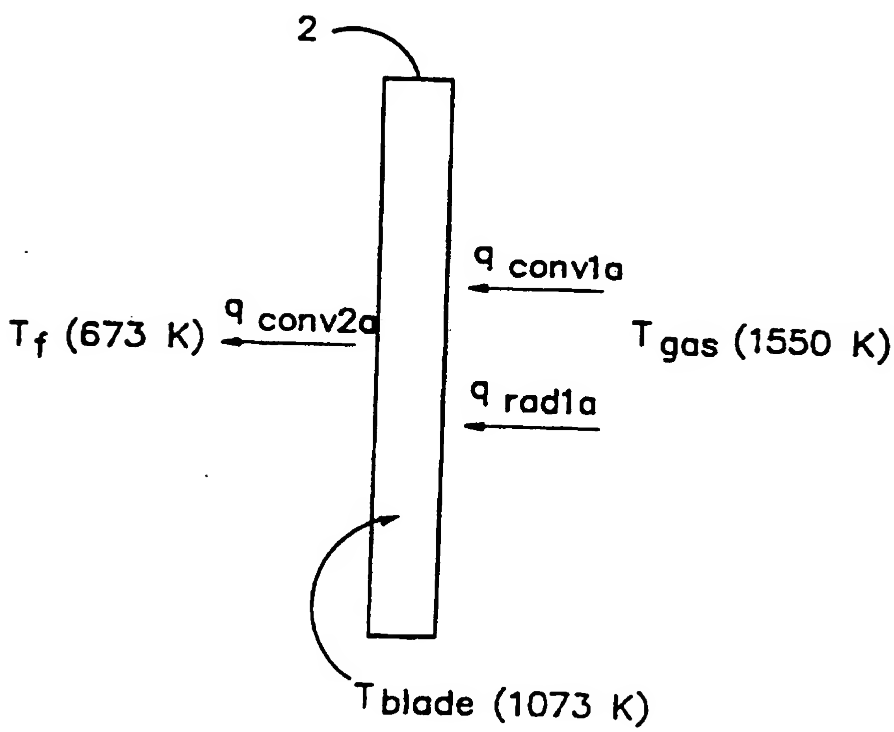


FIGURE 3(b)

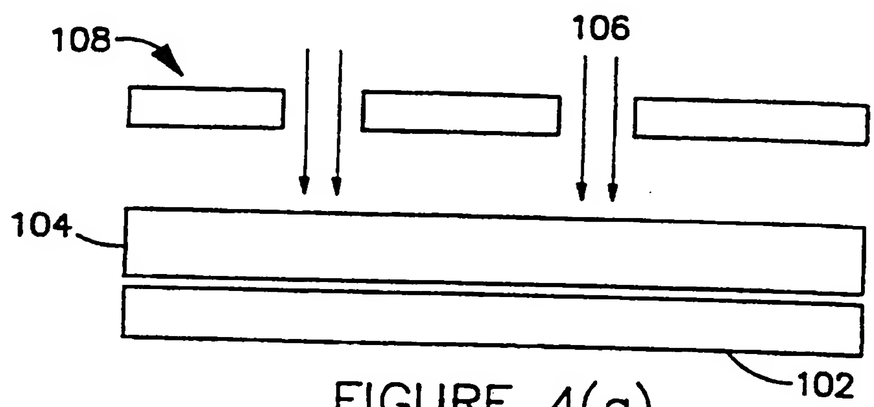


FIGURE 4(a)

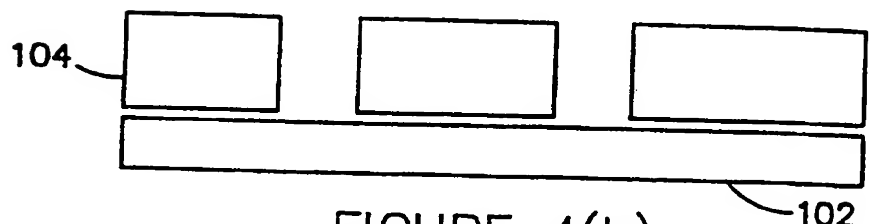


FIGURE 4(b)

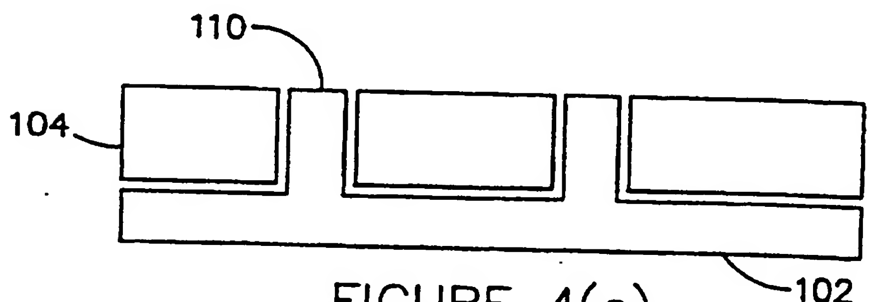


FIGURE 4(c)

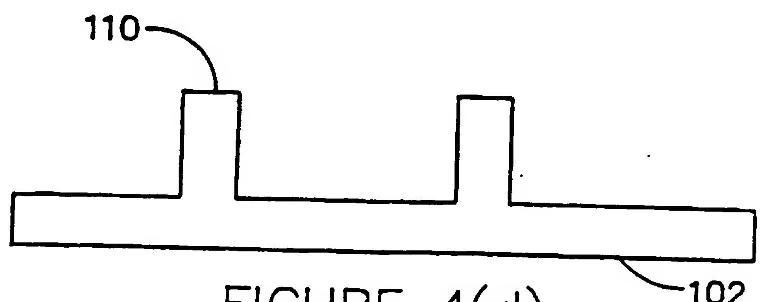


FIGURE 4(d)

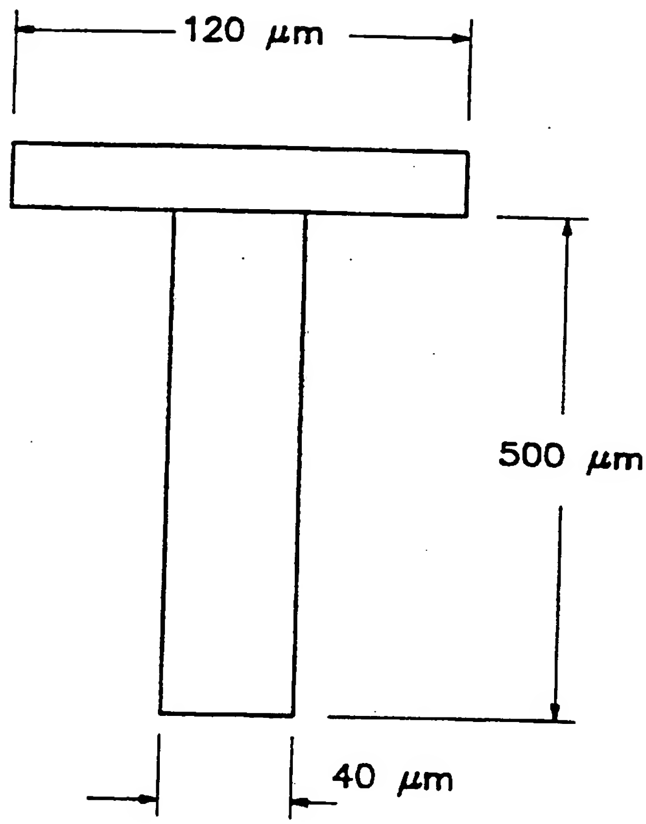


FIGURE 5(b)

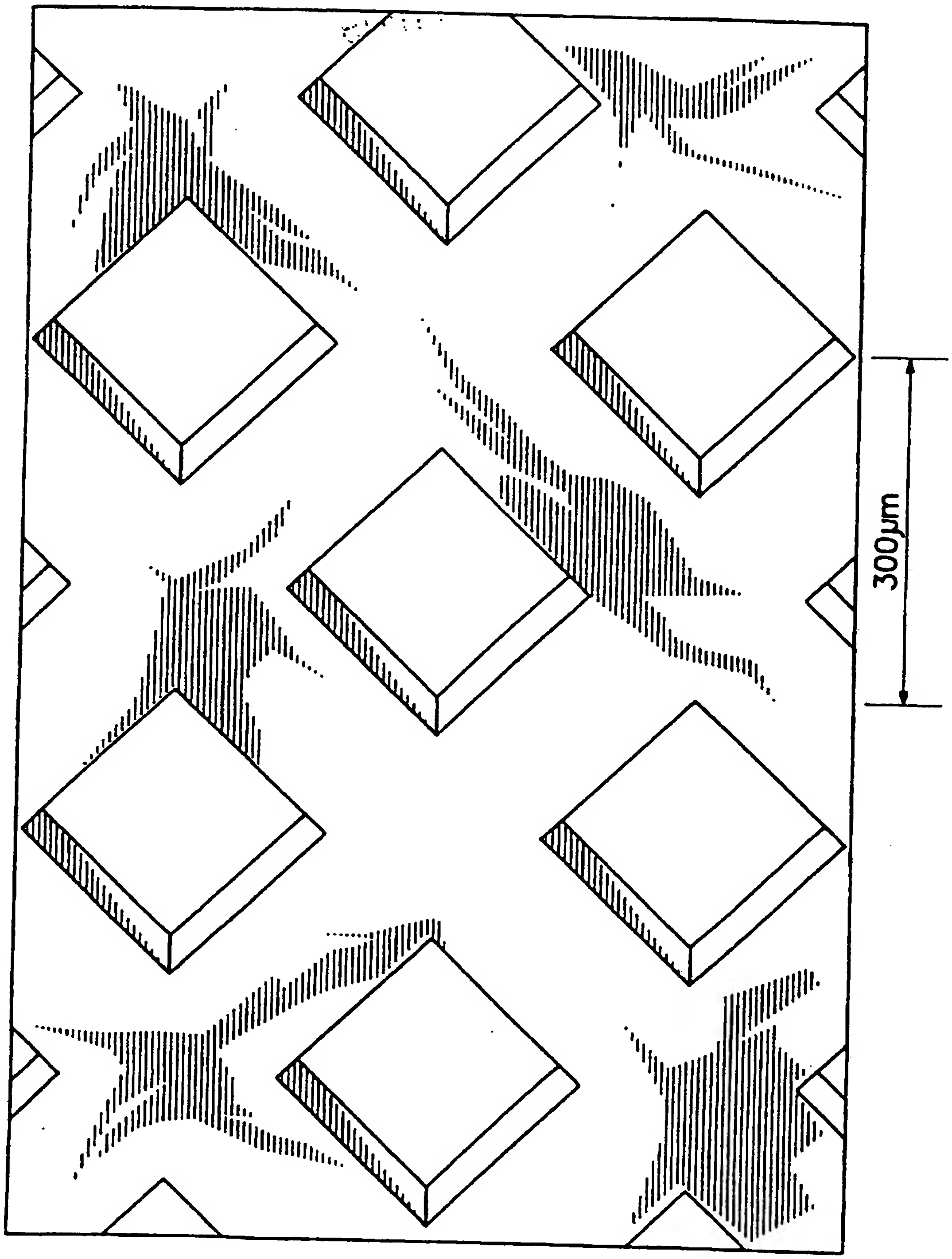


FIGURE 6